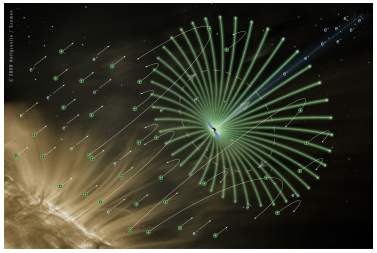


MISSION CONCEPT FOR ENTRY PROBES TO THE FOUR OUTER PLANETS BASED ON E-SAIL PROPULSION

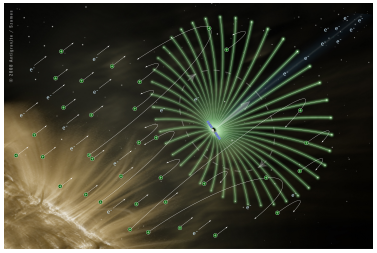
Jean-Pierre Lebreton (1,2) , Pekka Janhunen (3,*), Sini Merikallio (3,*), Petri Toivanen(3,*)

(1) ESA/ESTEC, RSSD, Noordwijk, Netherlands, , jean-pierre.lebreton@esa.int

(2) CNRS/LPC2E, Orleans, France, jean-pierre.lebreton@cnrs-orleans.fr

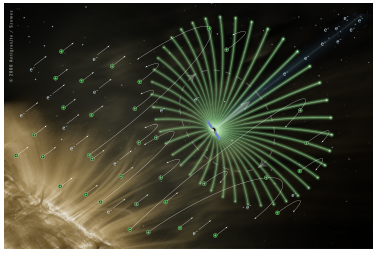
(3) Pekka Janhunen, Sini Merikallio, Petri Toivanen, Finnish Meteorological Institute, FMI, Helsinki, Finland

(*) EU Funding acknowledged



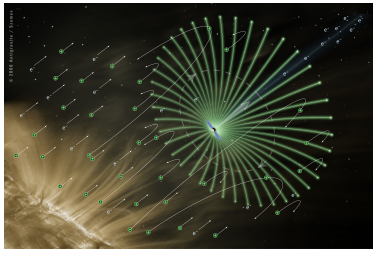
Outer Planet Science Goals

- **The science case for (shallow) entry probes in all Giant planets** is well made (e.g Atreya et al., Multiprobe exploration of the Giant Planets- Shallow Probes, Proc. IPPW-3, ESA WPP263, 2006) but can't realistically be contemplated in next decade with current budget/technology. **Several papers at this Workshop are addressing the science case.**
- **US Decadal Survey 2013-2022 OPAG recommendation:** New Frontiers class missions that should be considered in the interim include (but *not* in priority order) a shallow Saturn probe, an Io observer, a Titan *in-situ* explorer or probe, a Neptune/Triton/KBO flyby, and a Uranus orbiter (B. MacKinonn, White Paper)
- « **Our understanding of the exoplanet observations** is informed by our knowledge of the Solar System planets…… It is particularly important that we achieve a mature understanding of the Solar System giants planets, which can tell us about their intrinsic properties, including those properties that provide clues to the origin and development of the Solar System ». W. A. Traub, White Paper.
- **Outer Planet entry probes** were not proposed to ESA in response to Cosmic Vision Programme call for M3; european technology not mature.
- **Breakthroughs** need to happen to make giant planet entry probes affordable.. … within an international cooperation framework. **Can E-Sail help ?**



E-Sail: Artist's View

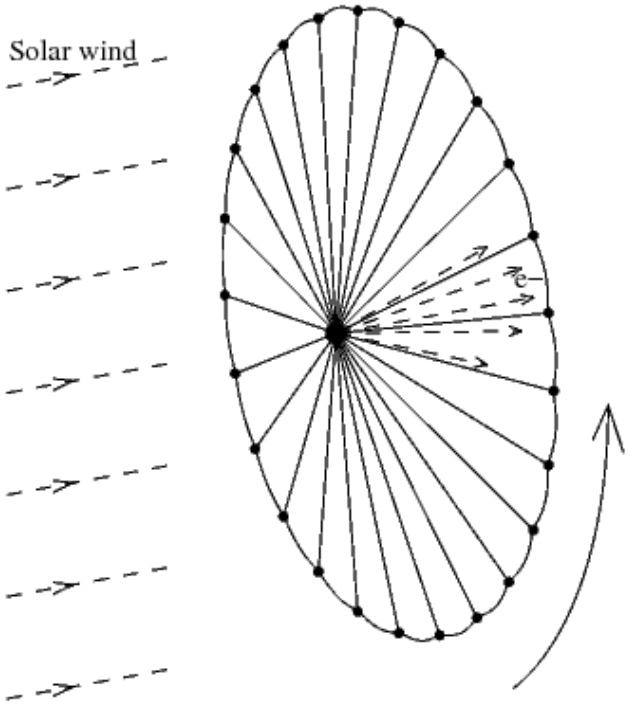
http://www.electric-sailing.fi

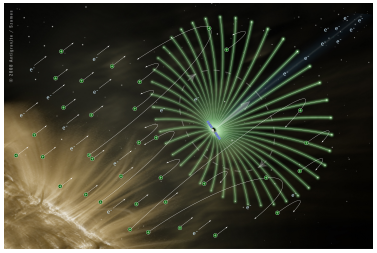


Electric Solar Wind Sail (E-Sail)

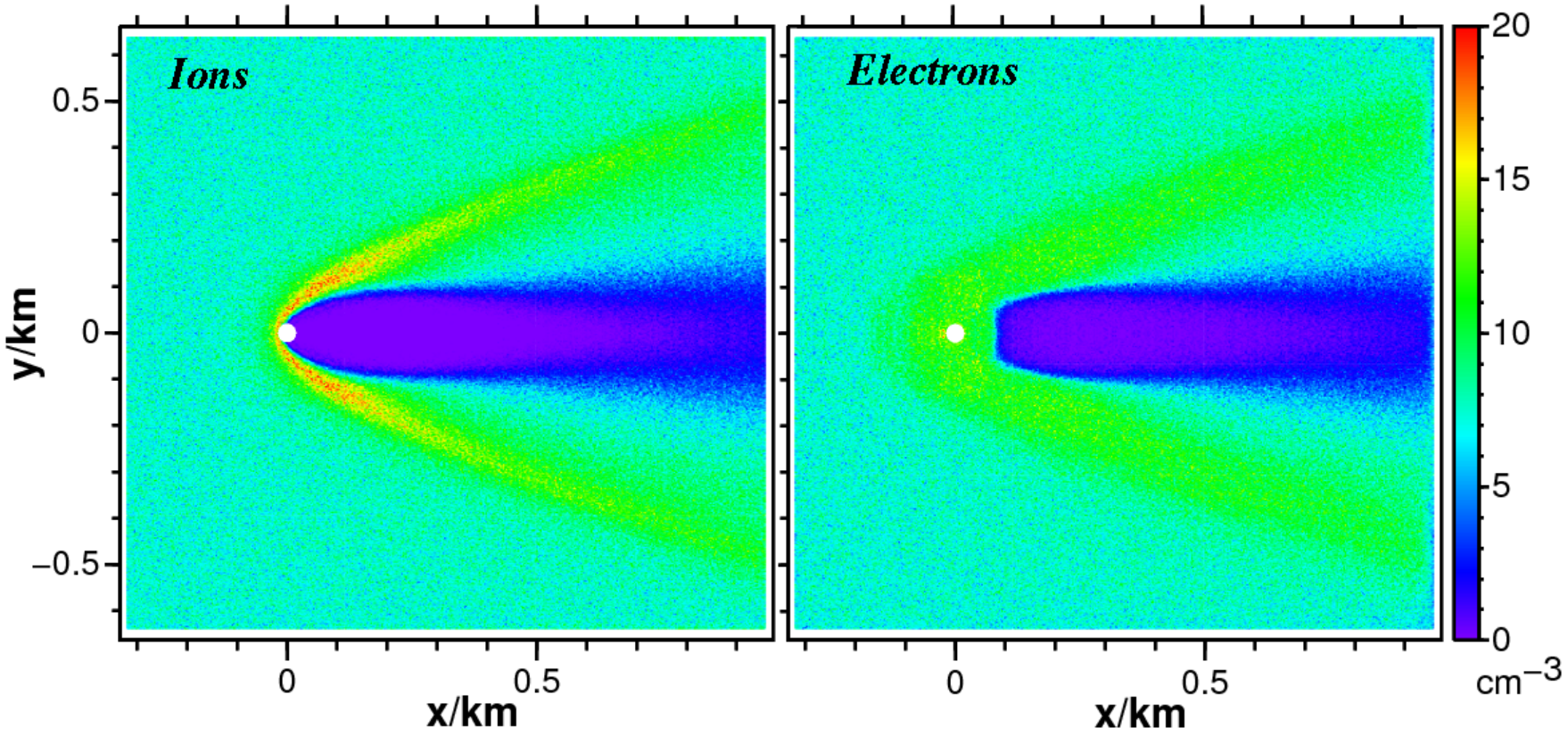
http://www.electric-sailing.fi

- Uses solar wind for spacecraft propulsion
- Coulomb interaction between solar wind and long, thin, positively charged tethers (10-20 km, 25-50 μ m wire, +20-40 kV)
- 1 N thrust from 100 kg system: 100-1000 times more efficient in 10-year mission than chemical rockets and ion engines
- Would become fastest and spatially largest man-made device
- Developed to TRL 4-5 in ESAIL FP7 (2011-2013)

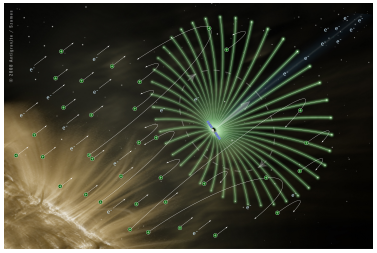




Plasma simulation of electric sail



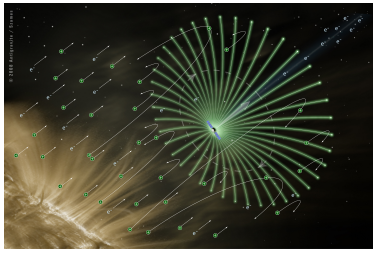
Simulation Conditions:
Solar Wind: 7.3 cm-3, 400 km/s; 10 eV
Tether voltage: 5.6 kV



Approximate thrust formula

$$\frac{dF}{dz} \approx \frac{2.2}{\log(R/r_w)} (V_0 - V_1) \sqrt{\epsilon_0 P_{\mathrm{dyn}}}$$

- V_0=20 kV (tether voltage)
- V_1=1 kV (solar wind proton energy)
- P_{dyn}=2 nPa (solar wind dynamic pressure)
- R=100 m (sheath radius)
- r_w=1 mm (effective electric width of tether)
- ==> dF/dz = 500 nN/m (obtained thrust per length)

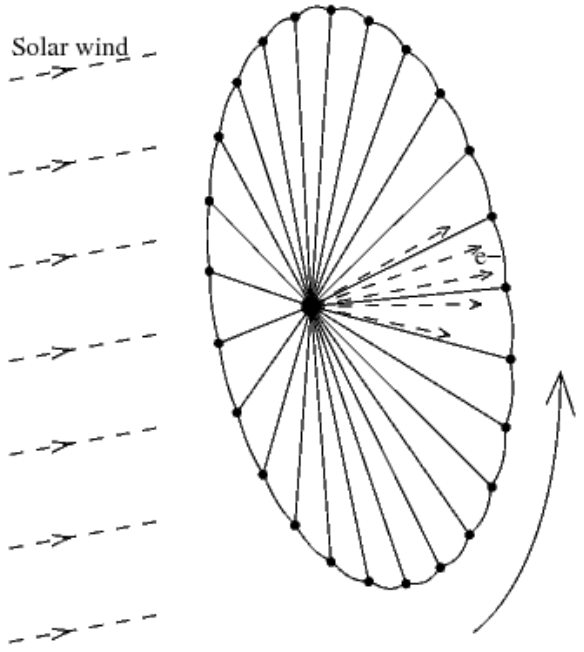


1 N E-Sail Reference

- 100 kg propulsion stage
  - 2000 km of tethers (e.g 100 x 20 km)
  - 25-50 um multi-wire tethers (based on Hoytether concept)
  - Spin deployment
  - Tethers charged at +20 kV
    - Solar Wind proton reflected
    - Solar Wind electron collected by wires, expelled by e-gun mounted on central bus.
  - No giant technology development step anticipated.

E-sail flight testing plans

- ESTCube-1 2012
  - Demonstrate deployment of 10 m tether
  - Measure E-sail effect
- Aalto-1 2013
  - Demonstrate somewhat longer tether
- Sounding rocket 2014?
  - Demonstrate mechanics of deployment
- Solar wind test mission (2016?)
  - Demonstrate propulsive flight
  - Looking for collaborators

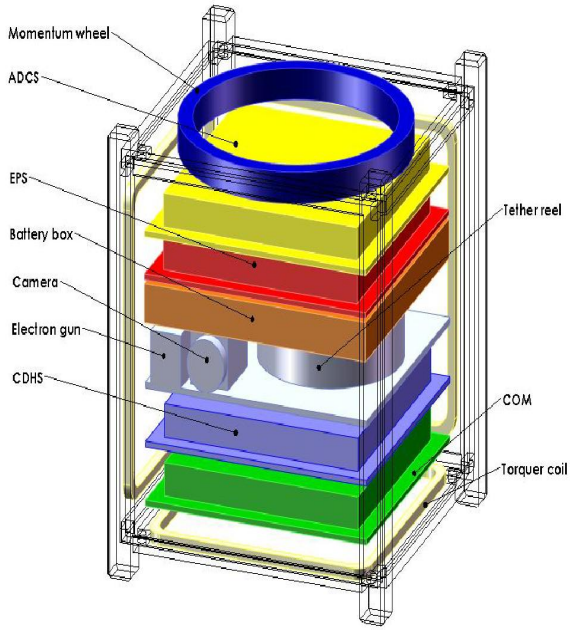


ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

ESTCube-1 and Aalto-1 test missions

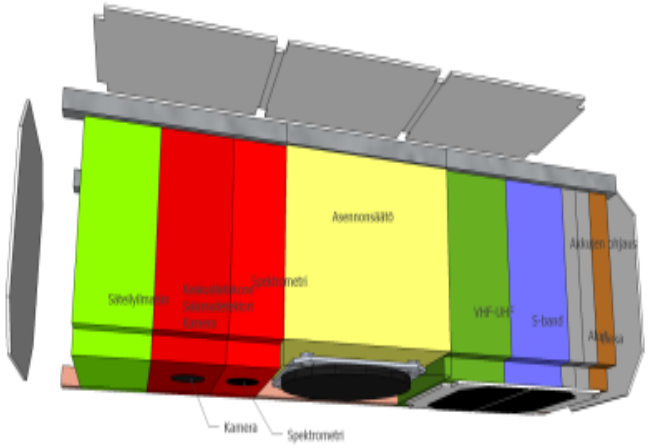
ESTCube-1

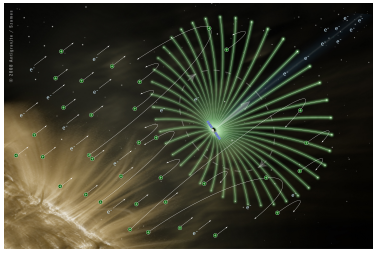
- Estonia's first satellite
- 10x10x10 cm cubesat,
  polar LEO orbit
- Measure E-sail force by 10 m
  Tether +-450 V voltage
- Launch 2012



Aalto-1

- Finland's first satellite
- 10x10x30 cm cubesat, polar LEO orbit
- Measure E-sail/plasma brake force
  and deorbit satellite
- Launch 2013





Giant planet entry probes: reference key parameters

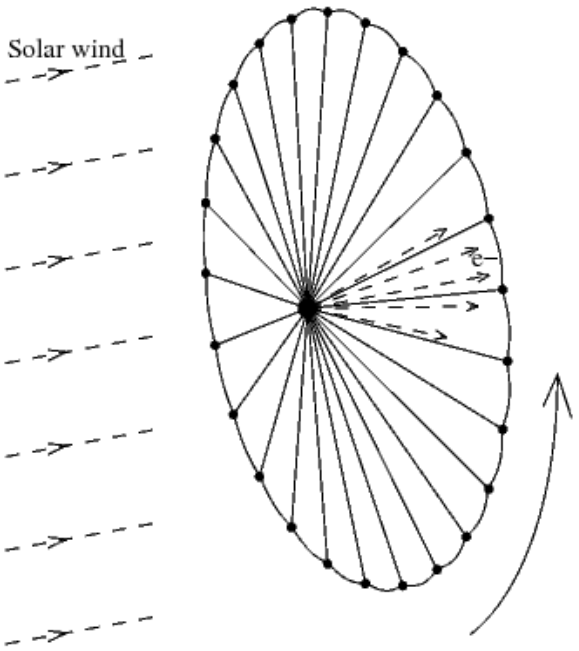
Giant planet atmospheric entry probe missions with baseline 1 N E-sail

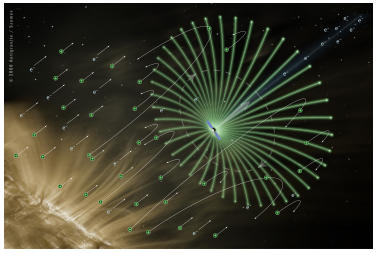
Jupiter Entry Probe		
Payload	Traveltime	Eq.atm.entry speed (subtracted rotation)
500 kg	1.0 years	53 km/s
1000 kg	1.6 years	49 km/s
1500 kg	2.5 years	47 km/s

Saturn Entry Probe		
Payload	Traveltime	Eq.atm.entry speed (subtracted rotation)
500 kg	1.7 years	37 km/s
1000 kg	2.8 years	30 km/s
1500 kg	4.6 years	27 km/s

Uranus Entry Probe		
Payload	Traveltime	Eq.atm.entry speed (subtracted rotation)
500 kg	3.1 years	36 km/s
1000 kg	5.3 years	25 km/s
1500 kg	9.6 years	20 km/s

Neptune Entry Probe		
Payload	Traveltime	Eq.atm.entry speed (subtracted rotation)
500 kg	4.6 years	38 km/s
1000 kg	8.0 years	28 km/s
1500 kg	14.9 years	23 km/s





Conclusions

- **Propellantless E-sail is under development**
  - 1 N @ 1 AU (scales 1/*r*), 100 kg
  - Spinoff of basic space plasma physics
- **May offer unique opportunity for the 4 giant planets**
  - Direct trajectory to target
  - Flexible launch window
  - Goes fast, arrives at high speed
  - Well suited for entry probes (fast entry)
  - Required launcher capability: <1000-2000 kg in Solar Wind (GTO, HEO) if individual launch
- **Recurrent cost if similar probe design suitable.**
- **Are all 4 giants reachable in 2025-2035 time frame ?**